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Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Terrestrial Plants

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ACRONYMS and ABBREVIATIONS

DOE	United States Department of Energy
EPA	United States Environmental Protection Agency
ER-L	Effects Range Low
HCl	Hydrochloric Acid
LCT	Lowest Concentration Tested
LOEC	Lowest Observed Effect Concentration
NOEC	No Observed Effect Concentration
PCB	Polychlorinated Biphenyl

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EXECUTIVE SUMMARY

One of the initial stages in ecological risk assessment for hazardous waste sites is the screening of contaminants to determine which of them are worthy of further consideration as "contaminants of potential concern." This process is termed "contaminant screening." It is performed by comparing measured ambient concentrations of chemicals to benchmark concentrations. Currently, no standard benchmark concentrations exist for assessing contaminants in soil with respect to their toxicity to plants. This report presents a standard method for deriving benchmarks for this purpose (phytotoxicity benchmarks), a set of data concerning effects of chemicals in soil or soil solution on plants, and a set of phytotoxicity benchmarks for 34 chemicals potentially associated with U.S. Department of Energy (DOE) sites. Chemicals that are found in soil at concentrations exceeding both the phytotoxicity benchmark and the background concentration for the soil type should be considered contaminants of potential concern.

1. INTRODUCTION

An important step in ecological risk assessment is screening the chemicals occurring on a site for contaminants of potential concern. Screening may be accomplished by comparing reported concentrations in media to a set of toxicological benchmarks. If a chemical concentration or the reported detection limit exceeds the screening benchmark, more analysis is needed to determine the hazards posed by that chemical (i.e., it is a contaminant of potential concern). If, however, the chemical concentration or its detection limit falls below the proposed benchmark, the chemical may be ignored during further study unless public concern or ancillary evidence suggest that it should be retained.

The purpose of this report is to present plant toxicity data and discuss their utility as benchmarks for determining the hazard to terrestrial plants caused by contaminants in soil. Benchmarks are provided for soils and solutions.

Tests of the toxicity of chemicals in the rooting medium of plants are conducted using a variety of rooting media. We have divided them into three categories: soil, solution, and other. Tests conducted in natural soils (even when brought into the laboratory, dried, sieved, fertilized, etc.) are assumed to be representative of the exposure of plants to contaminants measured in field soils. Tests conducted in nutrient solutions are assumed to be representative of exposures of plants to contaminants measured in soil solutions (e.g., from lysimeter samples or possibly from aqueous extracts of soil) or in very shallow groundwater (e.g., plants in the vicinity of seeps and springs). The other category includes media that are neither soils nor solutions, such as silica sand and vermiculite. Data from such studies are not clearly related to any contaminant measurements in ambient media. However, they are included in the review for purposes of comparison.

Soil benchmarks are based on data provided only by toxicity studies in either the field or pots. The reported toxic concentrations are not all equivalent to concentrations reported from field sites. Most of the soil concentrations of metals reported from waste sites are from extractions with hydrochloric acid (HCl) or other mineral acids which are intended to provide total concentrations. Similarly, concentrations of organic contaminants in waste site soils are total concentrations derived from rigorous solvent extractions. In some cases, toxicity tests report concentrations extracted from contaminated soils, but various extractants are used that may not yield total concentrations. More commonly, the concentrations reported are nominal concentrations of a soluble form (i.e., a highly bioavailable form) of the chemical added to soil.

Solution benchmarks include data from toxicity tests conducted using whole plants rooted in aqueous nutrient solutions. Tests are commonly conducted in this manner because plants are assumed to be exposed to contaminants in the solution phase of soil and the presence of soil in test systems reduces the experimenter's degree of control over exposure. Groundwater samples from waste sites are typically acidified before analysis to obtain total concentrations, but some samples are filtered before acidification.

In general, the concentrations in prefiltered samples are likely to be more comparable to the concentrations reported from solution toxicity tests and should be used if available.

These benchmarks are to serve for contaminant screening only. Plant toxicity may be affected by many variables: pH, Eh, cation exchange capacity, moisture content, interactions with other elements, and organic matter and clay content of the soil. In addition, different species react to different contaminants with varying degrees of toxicity, and the sensitivity of plants may be affected by its physiological condition. No systematic tests that thoroughly examine the effects of these variables on plant toxicity are known to these authors. An assessor must realize that these soil characteristics play a large part in plant toxicity and incorporate these site-specific considerations in the evaluation of the potential hazards of a chemical. If chemical concentrations reported in field soils that support vigorous and diverse plant communities exceed one or more of the benchmarks presented in this report or if a benchmark exceeds background soil concentrations, it is generally safe to assume that the benchmark is a poor measure of risk at that site.

2. METHODS

2.1 DATA

References on the toxicity of selected chemicals to terrestrial plants were obtained from searches of bibliographic data bases (BIOSIS, POL TOX I), a numeric data base (PHYTOTOX), review articles, and conventional literature searching. The target was reports of toxicity tests of individual chemicals in laboratory, greenhouse, or field settings.

Data presented in this report were derived mainly from primary sources. Secondary sources were used if the primary source cited in the secondary source was unavailable, if only a little data for a particular chemical were available, and if secondary sources suggested that a benchmark derived from limited primary source material was too high. The general criteria for inclusion of a study in the data set used to derive phytotoxicity benchmarks were:

1. Methodology was clearly stated (especially concentrations of applied chemicals) and followed in the experiment.

2. Results were quantified as measures of plant growth or yield (e.g., weight, height). Measures of metabolic activity or tissue chemical concentration were used if measures of growth or yield were not available for a particular chemical of interest.

3. Results were presented in numeric form or graphical presentations of data were clearly interpretable.

4. An unambiguous reduction existed in the measured parameter within the range of applied concentrations of the chemical of interest.

The data selected using these criteria were assigned to the following categories for analysis:

1. Chemical—The effects of individual chemicals of interest were analyzed. In the case of

metals, the metal itself is listed in the "Chemical" field, with the salt listed in the "Form" field. For organics, the specific compound is listed in the "Chemical" field, except in the case of polychlorinated biphenyl (PCB) for which the specific Aroclor mixture is listed in the "Form" field.

2. Growth Medium—Methodologies were divided into three general groupings of growth media:

   a. Solution: this category includes experiments in which the roots of plants were submerged in solutions of variable composition containing the chemical of interest. In most studies, plant growth nutrients were added. Solution pH was noted when given.

   b. Soil: this category includes soils derived from field soil profiles, regardless of subsequent preparation and experimental location. Soil pH and organic matter content were noted when given. Percentage organic carbon was converted to the more frequently cited measure of percentage organic matter, by the equation (Nelson and Sommers, 1982):

   $$\%\text{organic carbon} \times 2 = \%\text{organic matter}$$

   c. Other: this group is made up of alternative growth media such as pure quartz or silica sand, vermiculite, and peat moss. Medium pH was noted when given.

3. Plant Species—The analysis was limited to terrestrial vascular plants, mainly domestic cultivars. Plant growth stages were seed germination and early growth, seedling, or seedling to maturity (e.g., grains and vegetables).

4. Exposure duration—The durations of exposure of the test plants to chemicals of interest ranged from 2 to 279 days, with trees generally being exposed longer than plants with shorter life spans.

5. NOEC—The no observed effect concentration (NOEC) is defined here as the highest applied concentration of the chemical of interest which gave a reduction of 20% or less in a measured response.

6. LOEC—The lowest observed effect concentration (LOEC) is defined here as the lowest applied concentration of the chemical of interest which gave a greater than 20% reduction in a measured response. In some cases, the LOEC for the test was the lowest concentration tested (LCT) or the only concentration tested, as of when the EC_{50} was reported.

7. Response parameter—The majority of the responses were oven-dry weights of whole plants or their parts. Others included root length, plant height, relative growth rate, grain yield, seeds per plant, percent seed germination, and fresh and air-dry weights. Responses other than these growth and yield parameters were included only if growth or yield parameters were unavailable for a chemical. Transpiration rate, CO_2 uptake, and chlorophyll content of needles were recorded for methyl mercury; chlorophyll content of needles for mercury also was recorded.

2.2 SELECTION OF TYPES AND LEVELS OF EFFECTS

Growth and yield parameters were used for two reasons. First, they are the most common class of response parameters reported from phytotoxicity studies thereby using those parameters allowed for derivation of reasonably consistent benchmarks for a large number of contaminants. Second, growth and yield are ecologically significant responses both in terms of the plant populations and the ability of the biota to support higher trophic levels.

Twenty percent reduction in growth or yield was used as the threshold for significant effects to be consistent with other screening benchmarks for ecological risk assessment and with current regulatory practice (Suter et al., 1992). In brief, most regulatory criteria are based on concentrations that cause effects that are statistically significantly different from controls, which on average correspond to greater than 20% effects. In addition, regulatory actions may be based on comparisons of biological parameters measured on contaminated sites to those from reference sites. Differences between sites generally must be greater than 20% to be reliably detected in such studies. Therefore, the 20% effects level is treated as a conservative approximation of the threshold for regulatory concern.

2.3 DERIVATION OF BENCHMARKS

Because of the diversity of soils, plant species, chemical forms, and test procedures, it is not possible to estimate concentrations that would constitute a threshold for toxic effects on the plant communities at particular sites from published toxicity data. This situation is analogous to the problem of deriving benchmarks for sediments. In this report, the method used for deriving soil benchmarks is based on the National Oceanographic and Atmospheric Administration's method for deriving the Effects Range Low (ER-L) (Long and Morgan, 1990) which has been recommended as a sediment screening benchmark by U.S. Environmental Protection Agency (EPA) Region IV. The ER-L is the tenth percentile of the distribution of various toxic effects thresholds for various organisms in sediments.

This approach can be justified by assuming that the toxicity of a chemical in soil is a random variate, that the toxicity of contaminated soil at a particular site is drawn from the same distribution, and that the assessor should be 90% certain of protecting plants growing in the site soil. Any bias in the data set would mitigate against that assumption. In this implementation of the approach, the bias most likely to be significant is the use of soluble salts of metals in the toxicity tests which are likely to be more toxic than the mixture of forms encountered in field soils. That bias would result in conservative benchmark values. Other possible sources of bias include the use of predominately domestic plant species that may not be representative of plant species in general, use of predominately agricultural soils which may not be representative of soils in general, and the laboratory test conditions which may not be representative of field conditions. The direction and magnitude of these potential biases is unknown.

The phytotoxicity benchmarks were derived by rank ordering the LOEC values and then picking a number that approximated the tenth percentile. As with the ER-Ls, statistical fitting was not used because there was seldom sufficient data and because these benchmarks are to be used as screening values and do not require the consistency and precision of regulatory criteria.

If there were 10 or fewer values for a chemical, the lowest LOEC was used. If there were more than 10 values, the tenth percentile LOEC value was used. If the tenth percentile fell between LOEC values, a value was chosen by interpolation. In all cases, benchmark values were rounded to one significant figure.

Another possible source of benchmark values is values recommended in published reviews of the phytotoxicity literature. When primary literature is unavailable for a particular contaminant, concentrations identified in reviews as thresholds for phytotoxicity are used as benchmarks. In addition, when fewer than three LOEC values were found for a chemical in soil or solution, and a toxicity threshold from a review is lower than the lowest LOEC, the toxicity threshold is used as the benchmark for that chemical.

Any scheme for deriving a set of standard ecotoxicological benchmarks is based on assumptions that may be questioned by readers. The procedure used here is one that is consistent with current regulatory practice and contains a minimum of assumptions or factors. Those who care to make other assumptions or to add safety factors may make use of the data presented here to calculate their own benchmarks.

3. RESULTS

Results of the literature review are summarized in Table 1. Proposed screening benchmarks for phytotoxic effects of contaminants in soils and solutions are presented in Table 2.

4. RECOMMENDATIONS AND CONCLUSIONS

The values presented in Table 2 are intended for contaminant screening in the hazard identification (problem formulation) phase of ecological risk assessments. Chemicals with soil concentrations that exceed both the phytotoxicity benchmark for soil and the background soil concentration for the soil type, and which may be derived from waste disposal, are contaminants of potential concern. Background soil concentrations have been derived for the Oak Ridge Reservation and should be generated for other Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites as well. Similarly, soil solution or shallow groundwater concentrations that exceed both the phytotoxicity benchmark for solutions and the background water concentration for the aquifer, which may be derived from waste disposal, and to which plant roots may be exposed are contaminants of potential concern.

For baseline ecological risk assessments, and other assessments that may lead to regulatory actions, assessors should consult the primary sources of toxicity data and then determine the applicability of the data to their specific site. In addition, assessments should not blindly rely on laboratory toxicity data. Where phytotoxicity is suspected, phytotoxicity tests should be performed with the contaminated soil In addition, the site should be surveyed for signs of phytotoxicity such as inexplicable bare areas, low plant diversity, low plant vigor, or symptoms of toxic injury.

5. REFERENCES

Adema D. M. M. and L. Henzen. 1989. "A comparison of plant toxicities of some industrial chemicals in soil culture and soilless culture." *Ecotoxicol. Environ. Saf.* 18:219-29.

Aery, N. C. and S. Sarkar. 1991. "Studies on the effect of heavy metal stress on growth parameters of soybean." *J. Environ. Biol.* 12(1):15-24.

Aldrich, D. G., A. P. Vanselow, and G. R. Bradford. 1951. "Lithium toxicity in citrus." *Soil Sci.* 71:291-95.

Bowen, H. J. M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

Breeze, V. G. 1973. "Land reclamation and river pollution problems in the Croal Valley caused by waste from chromate manufacture." *J. Appl. Ecol.* 10:513-525.

Burke, D. G., K. Watkins, and B. J. Scott. 1990. "Manganese toxicity effects on visible symptoms, yield, manganese levels, and organic acid levels in tolerant and sensitive wheat cultivars." *Crop Sci.* 30:275-80.

Burton, K. W., E. Morgan, and A. Roig. 1984. "The influence of heavy metals upon the growth of sitka-spruce in South Wales forests." *Plant Soil.* 78:271-82.

Carlson, C. L., D. C. Adriano, and P. M. Dixon. 1991. "Effects of soil-applied selenium on the growth and selenium content of forage species." *J. Environ. Qual.* 20:363-68.

Carlson, R. W. and F. A. Bazzaz. 1977. "Growth reduction in American Sycamore (*Plantanus occidentalis L.*) caused by Pb-Cd interaction." *Environ. Pollut.* 12:243-53.

Carlson, R. W. and G. L. Rolfe. 1979. "Growth of rye grass and fescue as affected by lead-cadmium-fertilizer interaction." *J. Environ. Qual.* 8(3):348-352.

Carroll, M. D., and J. F. Loneragan. 1968. "Response of plant species to concentrations of zinc in solution." *Aust. J. Agric. Res.* 19:859-68.

Chapman, H. D. (ed.). 1966. *Diagnostic Criteria for Plants and Soils*. Univ. of California, Div. Agric. Sci. Cited in Bowen, H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

Chaudhry, F. M., A. Wallace, and R. T. Mueller. 1977. "Barium toxicity in plants." *Commun. Soil Sci. Plant Anal.* 8(9):795-97.

Cunningham, L. M. 1977. *Physiological and biochemical aspects of cadmium in soybean: The effects of induced Cd toxicity on the uptake and translocation of Zn, Fe, Mg, Ca and K.* Proc. Annual Conf. on Trace Substances in the Environment, pp. 133-45.

Deuel, L. E. and A. R. Swoboda. 1972. "Arsenic toxicity to cotton and soybeans." *J. Environ. Qual.* 1:317-20.

Dixon, R. K. 1988. "Response of ectomycorrhizal *Quercus rubra* to soil cadmium, nickel and lead." *Soil Biol. Biochem.* 20(4):555-59.

Dvorak, A. J., B. G. Lewis, et al. 1978. *Impacts of coal-fired power plants on fish, wildlife, and their habitats.* U.S. Fish and Wildlife Service Report No. FWS/OBS-78/29, Ann Arbor, Mich.

U.S. Environmental Protection Agency (EPA). 1975. *Preliminary Investigation of Effects of Boron, Indium, Nickel, Selenium, Tin, Vanadium, and Their Compounds, Vol. VI, Vanadium.* U.S. EPA Report No. EPA-560/2-75-005f. Cited in EPA. 1980. *A Screening Procedure for the Impacts of Air Pollution Sources on Plants, Soils, and Animals.* EPA 450/2-81-078. Washington, D.C.

Gall, O. E. and R. M. Barnette. 1940. "Toxic limits of replaceable zinc to corn and cowpeas grown of three Florida soils." *J. Am. Soc. Agron.* 32:23-32.

Görransson, A. and T. D. Eldhuset. 1991. "Effects of aluminum on growth and nutrient uptake of small *Picea abies* and *Pinus sylvestris* plants." *Trees.* 5:136-42.

Gupta, D. B. and S. Mukherji. 1977. "Effects of toxic concentrations of copper on growth and metabolism of rice seedlings." *Z. Pflanzenphysiol. Bd.* 82:95-106.

Haghiri, F. 1973. "Cadmium uptake by plants." *J. Environ. Qual.* 2(1):93-95.

Hara, T., Y. Sonoda, and I. Iwai. 1976. "Growth response of cabbage plants to transition elements under water culture conditions." *Soil Sci. Plant Nutr.* 22(3):307-315.

Hassett, J. J., J. E. Miller, and D. E. Koeppe. 1976. "Interaction of lead and cadmium on maize root growth and uptake of lead and cadmium by roots." *Environ. Pollut.* 11:297-302.

Hooper, M. C. 1937. "An investigation of the effect of lead on plants." *Ann. Appl. Biol.* 24:690-695.

Hutton, E. M., W. T. Willams, and C. S. Andrew. 1978. "Differential Tolerance to manganese in introduced and bred lines of *Macroptilium atropurpureum.*" *Aust. J. Agric. Res.* 29:67-79.

John, M. K., H. H. Chuah, and C. J. VanLaerhoven. 1977. "Boron response and toxicity as affected by soil properties and rates of boron." *Soil Sci.* 124:34-39.

Keisling, T. C., D. A. Lauer, M. E. Walker, and R. J. Henning. 1977. "Visual, tissue, and soil factors associated with Zn toxicity of peanuts." *Agronomy J.* 69(5):765-69.

Keltjens, W. G. 1990. "Effects of aluminum on growth and nutrient status of Douglas-fir seedlings grown in culture solution." *Tree Physiol.* 6:165-75.

Khalid, B. Y. and J. Tinsley. 1980. "Some effects of nickel toxicity on rye grass." *Plant Soil.* 55:139-44.

Khan, D. H. and B. Frankland. 1983. "Effects of cadmium and lead on radish plants with particular reference to movement of metals through soil profile and plant." *Plant Soil.* 70:335-345.

Khan, D. H. and B. Frankland. 1984. "Cellulolytic activity and root biomass production in some metal-contaminated soils." *Environ. Pollut.* 33:63-74.

Kitagishi, K. and I. Yamane (eds.). 1981. *Heavy Metal Pollution of Soils of Japan.* Japan Sci. Soc. Press, Japan. Cited in A. Kabata-Pendias and H. Pendias (eds.). 1984. *Trace Elements in Soils and Plants.* CRC Press, Boca Raton, Florida.

Kloke, A. 1979. *Content of arsenic, cadmium, chromium, fluorine, lead, mercury, and nickel in plants grown on contaminated soil.* Paper presented at United Nations-ECE Symp. Effects of Air-borne Pollution on Vegetation. Warsaw. Cited in A. Kabata-Pendias and H. Pendias (eds.). 1984. *Trace Elements in Soils and Plants.* CRC Press, Inc. Boca Raton, Florida.

Kovalskiy, V. V. 1974. "Geochemical environment, health and diseases. **In:** *Trace Substances in Environmental Health,* Vol. 8, D. D. Hemphill (ed.) Univ. Missouri, Columbia, MO., p. 137.

Lamoreaux, R. J. and W. R. Chaney. 1977. "Growth and water movement in silver maple seedlings affected by cadmium." *J. Environ. Qual.* 6(2):201-04.

Langheinrich, U., R. Tischner, and D. L. Godbold. 1992. "Influence of a high Mn supply on Norway spruce [*Picea abies* (L.) Karst.] seedlings in relation to the nitrogen source." *Tree Physiol.* 10:259-71.

Lata, K. and B. Veer. 1990. "Phytotoxicity of Zn amended soil to *Spinacia* and *Coriandrum.*" *Acta Bot. Indica.* 18:194-198.

Le Bot, J., E. A. Kirkby, and M. L. van Beusichem. 1990. "Manganese toxicity in tomato plants: Effects on cation uptake and distribution." *J. Plant Nutr.* 13(5):513-25.

Lee, R. C. and N. R. Page. 1967. "Soil factors influencing the growth of cotton following peach orchards." *Agronomy J.* 59:237-40.

Lewis, J. C. and W. L. Powers. 1941. "Antagonistic action of chlorides on the toxicity of iodides to corn." *Plant Physiol.* 393-98.

Lin, Z. and D. L. Myhre. 1991. "Differential response of citrus rootstocks to aluminum levels in nutrient solutions: I. Plant growth." *J. Plant Nutr.* 14(11):1223-38.

Linzon, S. N. 1978. *Phytotoxically excessive levels for contaminants in soil and vegetation.* Report of Ministry of the Environment. Ontario, Canada. Cited in A. Kabata-Pendias and H.

Pendias (eds.). 1984. *Trace Elements in Soils and Plants*. CRC Press, Boca Raton, Florida.

Long, R. E. and L. G. Morgan. 1990. *The potential for biological effects of sediment-sorbed contaminants tested in the national status and trends program.* NOAA Technical Memorandum NOS OMA 52.

Macleod, L. B. and L. P. Jackson. 1967. "Aluminum tolerance of two barley varieties in nutrient solution, peat, and soil culture." *Agronomy J.* 59:359-63.

Martin, A. L. 1937. "A comparison of the effects of tellurium and selenium on plants and animals." *Am. J. Bot.* 24:198-203

Martin, A. L. 1937. "Toxicity of selenium to plants and animals." *Am. J. Bot.* 23:471-483.

McLean, F. T. and B. E. Gilbert. 1927. "The relative aluminum tolerance of crop plants." *Soil Sci.* 24:163-74.

Miles, L. J. and G. R. Parker. 1979. "Heavy metal interaction for *Andropogon scoparius* and *Rudbeckia hirta* grown on soil from urban and rural sites with heavy metals additions." *J. Environ. Qual.* 8(4):443-49.

Miller, J. E., J. J. Hassett, and D. E. Koeppe. 1977. "Interactions of lead and cadmium on metal uptake and growth of corn plants." *J. Environ. Qual.* 6(1):18-20.

Muramoto, S., H. Nishizaki, and I. Aoyama. 1990. "The critical levels and the maximum metal uptake for wheat and rice plants when applying metal oxides to soil." *J. Environ. Sci. Health, Part B* 25(2):273-80.

Nelson, D. W., and L. E. Sommers. 1982. "Total carbon, organic carbon, and organic matter." **In:** *Methods of Soil Analysis, Part 2.* p. 574. ASA/SSSA. Madison, WI.

Newton, H. P. and S. J. Toth. 1952. "Response of crop plants to I and Br." *Soil Sci.* 73:127-34.

Overcash, R. M., J. B. Weber, and M. L. Miles. 1982. *Behavior of organic priority pollutants in the terrestrial system: Di-n-butyl phthalate ester, toluene, and 2,4 dinitrophenol.* UNC-WRRI-82-171. Water Resources Research Institute, Univ. North Carolina.

Page, A. L., F. T. Bingham, and C. Nelson. 1972. "Cadmium absorption and growth of various plant species as influenced by solution cadmium concentration." *J. Environ. Qual.* 1(3):288-91.

Patel, P. M., and A. Wallace, and R. T. Mueller. 1976. "Some effects of copper, cobalt, cadmium, zinc, nickel, and chromium on growth and mineral element concentration in chrysanthemum." *J. Am. Soc. Hortic. Sci.* 101(5):553-556.

Romney, E. M. and J. D. Childress. 1965. "Effects of beryllium in plants and soil." *Soil Sci.* 100(2):210-17.

Romney, E. M., J. D. Childress, and G. V. Alexander. 1962. "Beryllium and the growth of bush beans." *Science*. 185:786-87.

Sadana, U. S. and B. Singh. 1987a. "Yield and uptake of cadmium, lead and zinc by wheat grown in soil polluted with heavy metals." *J. Plant Sci. Res*. 3:11-17.

Sadana, U. S. and B. Singh. 1987b. "Effect of zinc application of yield and cadmium content of spinach (*Spinacea oleracea L.*) grown in a cadmium-polluted soil." *Ann. Biol*. 3:59-60.

Scharrer, K. 1955. *Biochemie der Spurenelemente*. Parey, Berlin. Cited in Bowen, H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

Schlegel, H., D. L. Godbold, and A. Huttermann. 1987. "Whole plant aspects of heavy metal induced changes in CO2 uptake and water relations of spruce (*Picea abies*) seedlings." *Physiol. Plantarum*. 69:265-70.

Schroeder, H. A., J. J. Balassa, and I. H. Tipton. 1964. "Abnormal trace elements in man: Tin." *J. Chronic Dis*. 17:483-502.

Singh, B. B. 1971. "Effect of vanadium on the growth, yield and chemical composition of maize (*Zea mays L.*)." *Plant Soil*. 34:209-12.

Singh, A., N. K. Goyal, and A. P. Gupta. 1991. "Effect of cadmium and farm yard manure on the concentration and uptake of zinc by wheat in texturally different soils." *Crop Res*. 4(2):199-205.

Smith, G. S. and J. H. Watkinson. 1984. "Selenium toxicity in perennial ryegrass and white clover." *New Phytol*. 97:557-64.

Spencer, E. L. 1937. "Frenching of tobacco and thallium toxicity." *Am. J. Bot*. 24:16-24.

Stiborova, M., R. Hromadkova, and S. Leblova. 1986. "Effect of ions of heavy metals on the photosynthetic characteristics of maize (*Zea mays L.*)." *Biologia*. 41(12):1221-28.

Stiles, W. 1958. *Encyclopaedia of Plant Physiology, Vol. 4*. Springer-Verlag, N.Y. Cited in Bowen, H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

Strek, J. H. and J. B Weber. 1980. *Absorption and translocation of polychlorinated biphenyls (PCBs) by weeds*. Proc. South. Weed Sci. Soc. 33:226-232.

Strek, J. H. and J. B. Weber. 1982. "Adsorption and reduction in bioactivity of polychlorinated biphenyl (Aroclor 1254) to redroot pigweed by soil organic matter and montmorillonite clay." *Soil Sci. Soc. Am. J*. 46:318-22.

Struckmeyer, B. E., L. A. Peterson, and F. Hsi-Mer Tai. 1969. "Effects of copper on the composition and anatomy of tobacco." *Agronomy J*. 61:932-936.

Suter, G. W., II. 1992. *Approach and strategy for performing ecological risk assessments for the Department of Energy Oak Ridge Field Office Environmental Restoration Program.* ES/ER/TM-33. Oak Ridge National Laboratory, Environmental Science Division.

Traynor, M. F. and B. D. Knezek. 1973. *Effects of nickel and cadmium contaminated soils on nutrient composition of corn plants.* Proc. Annual Conf. on Trace Substances in the Environment. 7:82-87.

Trelease, S. F. and H. M. Trelease. 1938. "Selenium as a stimulating and possibly essential element for indicator plants." *Am. J. of Bot.* 25:372-79.

Turner, M. A. 1973. "Effect of cadmium treatment on cadmium and zinc uptake by selected vegetable species." *J. Environ. Qual.* 2(1):118-19.

Turner, M. A. and R. H. Rust. 1971. *Effects of chromium on growth and mineral nutrition of soybeans.* Soil Sci. Soc. Am. Proc. 35:755-58.

Wallace, A. 1979. "Excess trace metal effects on calcium distribution in plants." *Commun. Soil Sci. Plant Anal.* 10:473-79.

Wallace, A. and E. M. Romney. 1977. "Aluminum toxicity in plants grown in solution culture." *Commun. Soil Sci. Plant Anal.* 8(9):791-94

Wallace, A., G. V. Alexander, and F. M. Chaudhry. 1977a. "Phytotoxicity of cobalt, vanadium, titanium, silver, and chromium." *Commun. Soil Sci. Plant Anal.* 8(9):751-56.

Wallace, A., G. V. Alexander, and F. M. Chaudhry. 1977b. "Phytotoxicity and some interactions of the essential trace metals iron, manganese, molybdenum, zinc, copper, and boron." *Commun. Soil Sci. Plant Anal.* 8(9):741-50.

Wallace, A., R. M. Romney, J. W. Cha, S. M. Soufi, and F. M. Chaudhry. 1977c. "Lithium toxicity in plants." *Commun. Soil Sci. Plant Anal.* 8(9):773-80.

Wallace, A., R. M. Romney, J. W. Cha, S. M. Soufi, and F. M. Chaudhry. 1977d. "Nickel phytotoxicity in relationship to soil pH manipulation and chelating agents." *Commun. Soil Sci. Plant Anal.* 8(9):757-64.

Weber, J. B. and E. Mrozek, Jr. 1979. "Polychlorinated biphenyls: Phytotoxicity, absorption and translocation by plants, and inactivation by activated carbon." *Bull. Environ. Contam. Toxicol.* 23:412-17.

Wheeler, D. M. and J. M. Follet. 1991. "Effect of aluminum on onions, asparagus and squash." *J. Plant Nutr.* 14(9):897-912.

White, M. C., R. L. Chaney, and A. M. Decker. 1979. "Differential cultivar tolerance in soybean to phytotoxic levels of soil Zn. II. Range of Zn additions and the uptake and translocation of Zn, Mn, Fe, and P." *Agronomy J.* 71:Jan-Feb.

Wickliff, C., and H. J. Evans. 1980. "Effect of cadmium on the root and nodule ultrastructure of *Alnus rubra*." *Environ. Pollut., Ser. A*. 21:287-306.

Wickliff, C., H. J. Evans, K. R. Carter, and S. A. Russell. 1980. "Cadmium effects on the nitrogen fixation system of red alder." *J. Environ. Qual.* 9(2):180-183.

Wong, M. H. and A. D. Bradshaw. 1982. "A comparison of the toxicity of heavy metals, using root elongation of rye grass, *Lolium perenne*." *New Phytol.* 92:255-61.

Wong, M. H. and W. M. Lau. 1985. "Root growth of *Cynodon* and *Eleusine indica* collected from motorways at different concentrations of lead." *Environ. Res.* 36:257-67.

Table 1. Phytotoxicity data used in the derivation of soil benchmarks (NOEC and LOEC concentrations are mg/kg of the element. Duration is measured in days.)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Aluminum	Soil	$AlCl_3$	Barley	24	6	12		Dry wgt. root/shoot	4	Macleod and Jackson. 1967.
Aluminum	Soil	$AlCl_3$	Barley	24	6	12		Dry wgt. plant	6	Macleod and Jackson. 1967.
Aluminum	Soil	$AlCl_3$	Barley	24	6	12		Dry wgt. root/shoot	4	Macleod and Jackson. 1967.
Aluminum	Solution	$Al_2(SO_4)_3$	Asparagus		0.05	0.13		Dry wgt. root/shoot	4.7	Wheeler and Follet. 1991.
Aluminum	Solution	$Al_2(SO_4)_3$	Rice	13	0.27	2.7		Dry wgt. root/shoot		Wallace and Romney. 1977.
Aluminum	Solution	$AlCl_3+Al(NO_3)_3$	Spruce	21	5.4	8.1		Rel. gwth. rate root	3.8	Goransson and Eldhuset. 1991.
Aluminum	Solution	$Al_2(SO_4)_3$	Soybean	13	0.27	2.7		Dry wgt. root/shoot		Wallace and Romney. 1977.
Aluminum	Solution	$Al_2(SO_4)_3$	Lettuce	56	0.9	1.8		Air dry wgt. plant	4.3	McLean and Gilbert 1927
Aluminum	Solution	$Al_2(SO_4)_3$	Lemon	60	4.8	8.3		Fresh wgt; root length	4	Lin and Myhre. 1991.
Aluminum	Solution	$Al_2(SO_4)_2$	Turnip	77	3.6	7.2		Air dry wgt. shoot	4.3	McLean and Gilbert 1927.
Aluminum	Solution	$Al_2(SO_4)_3$	Rye	70		3.5	LCT	Air dry wgt. root	4.5	McLean and Gilbert. 1927.
Aluminum	Solution	$Al_2(SO_4)_3$	Lettuce	56	1.8	2.7		Air dry wgt. plant	4.3	McLean and Gilbert 1927
Aluminum	Solution	$Al_2(SO_4)_3$	Orange	60	4.8	8.3		Fresh wgt; root length	4	Lin and Myhre. 1991.
Aluminum	Solution	$Al_2(SO_4)_3$	Beet	77		1.8	LCT	Air dry wgt. plant	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	$Al_2(SO_4)_3$	Barley	77		1.8	LCT	Air dry wgt. root/shoot	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	$AlCl_3+Al(NO_3)_3$	Pine	21	161.9	269.8		Rel. gwth. rate shoot	3.8	Goransson and Eldhuset 1991.
Aluminum	Solution	$Al_2(SO_4)_3$	Radish	77	1.8	3.6		Air dry wgt. root/shoot	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	$AlCl_3$	Barley	30	4	6		Dry wgt. root/shoot	4.3	Macleod and Jackson. 1967.
Aluminum	Solution	$Al_2(SO_4)_3$	Rye	63		1.8	LCT	Air dry wgt. root	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	$AlCl_3$	Douglas fir	279	16	32		Dry wgt. root/lgth.	3.5	Keltjens. 1990.
Aluminum	Solution	$Al_2(SO_4)_3$	Lettuce	42	0.54	1.08		Air dry wgt. shoot	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	$Al_2(SO_4)_3$	Beet	126		1.8	LCT	Air dry wgt. plant	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	$Al_2(SO_4)_3$	Citrumelo	60	4.8	8.3		Fresh wgt. plant	4	Lin and Myhre. 1991.
Aluminum	Solution	$Al_2(SO_4)_3$	Carrot	126		3.6	LCT	Air dry wgt. plant	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	$Al_2(SO_4)_3$	Carrot	126		3.6	LCT	Air dry wgt. plant	4.3	McLean and Gilbert. 1927.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Aluminum	Solution	Al2(SO4)3	Douglas fir	279	4	8		Dry wgt. root	7.5	Keltjens. 1990.
Aluminum	Solution	Al2(SO4)3	Oat	63	3.6	7.2		Air dry wgt. root/shoot	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	Al2(SO4)3	Squash	26	0.13	0.27		Dry wgt. root	4.7	Wheeler and Follet. 1991.
Aluminum	Solution	Al2(SO4)3	Beet	126		1.8	LCT	Air dry wgt. plant	0	McLean and Gilbert. 1927.
Aluminum	Solution	KAl(SO4)2	Rye grass	14		0.63	LCT	Lgth. longest root	7	Wong and Bradshaw. 1982.
Aluminum	Solution	Al2(SO4)3	Citrange	60	0.11	2.7		Root length	4	Lin and Myhre. 1991.
Aluminum	Solution	Al2(SO4)3	Carrot	126		3.6	LCT	Air dry wgt. plant	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	Al2(SO4)3	Orange	60	8.3	24.4		Fresh wgt; root length	4	Lin and Myhre. 1991.
Aluminum	Solution	Al.2(SO4)3	Cabbage	98		7.2	LCT	Air dry wgt. plant	4.3	McLean and Gilbert. 1927.
Aluminum	Solution	Al2(SO4)3	Barley	30	8	10		Dry wgt. root/shoot	4.3	Macleod and Jackson. 1967
Aluminum	Solution	Al2(SO4)3	Onion	31		0.05	LCT	Dry wgt. root/shoot	4.7	Wheeler and Follet. 1991.
Antimony	Surface soil					5		Phytotoxic		Kloke. 1979.
Arsenic	Black clay	As2O3	Soybean	42		22.4	LCT	Dry wgt. shoot		Deuel and Swoboda. 1972.
Arsenic	Black clay	As2O3	Cotton	42	67.2	89.6		Dry wgt. shoot		Deuel and Swoboda. 1972.
Arsenic	Fine sandy loam	As2O3	Cotton	42		11.2	LCT	Dry wgt. shoot		Deuel and Swoboda 1972
Arsenic	Fine sandy loam	As2O3	Soybean	42		11.2	LCT	Dry wgt. shoot		Deuel and Swoboda. 1972
Arsenic	Solution					0.02	LCT	Phytotoxic		Scharrer. 1955.
Barium	Loam	Ba(NO3)2	Barley	14		500	LCT	Dry wgt. plant		Chaudhry, et al. 1977.
Barium	Loam	Ba(NO3)2	Bush beans	14	100	2000		Dry wgt. plant		Chaudhry, et al. 1977.
Barium	Solution					500	LCT	Phytotoxic		Chapman. 1966.
Beryllium	Solution	BeCl2	Barley	20		2	LCT	Dry wgt. plant	5.3	Romney and Childress. 1965.
Beryllium	Solution	BeCl2	Alfalfa	54	2	4		Dry wgt. plant	5.3	Romney and Childress. 1965
Beryllium	Solution		Bean	48		0.5	LCT	Dry wgt. plant	5.3	Romney, et al. 1962.
Beryllium	Solution	BeCl2	Pea	24		2	LCT	Dry wgt. plant	5.3	Romney and Childress. 1965.
Beryllium	Solution	BeCl2	Lettuce	28		2	LCT	Dry wgt. plant	5.3	Romney and Childress. 1965

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Beryllium	Surface soil					10		Phytotoxic		Kloke. 1979.
Bismuth	Solution					27		Phytotoxic		Scharrer. 1955.
Boron	Muck	H3BO3	Corn	28	10	50		Dry wgt. shoot	4.5	John, et al. 1977.
Boron	Silt loam	H3BO3	Corn	28	10	50		Dry wgt. shoot	5.7	John, et al. 1977.
Boron	Silt loam	H3BO3	Corn	28		0.5	LCT	Dry wgt. shoot	5.7	John, et al. 1977.
Boron	Solution					1	LCT	Phytotoxic		Bowen. 1979.
Boron	Solution	H3BO3	Bush beans	16	1.08	5.4		Dry wgt. root/leaves		Wallace, et al. 1977b.
Bromine	Solution					15	LCT	Phytotoxic		Chapman. 1966.
Bromine	Surface soil					10		Phytotoxic		Kloke. 1979
Cadmium	Alluvial soil	CdO	Rice	105	30	100		Dry wgt. root/stem	5.95	Muramoto, et al. 1990.
Cadmium	Alluvial soil	CdO	Wheat	161	10	30		Yield grain	5.95	Muramoto, et al. 1990.
Cadmium	Brown earth soil	CdCl2+CdO(1:1)	Radish	42		50	LCT	Dry wgt. root	4.6	Khan and Frankland. 1984
Cadmium	Brown earth soil	CdCl2	Radish	42		10	LCT	Dry wgt. root/shoot	5.4	Khan and Frankland. 1983.
Cadmium	Brown earth soil	CdCl2	Oat	42		10	LCT	Dry wgt. root	5.4	Khan and Frankland. 1984.
Cadmium	Brown earth soil	CdO	Wheat	42		100	LCT	Dry wgt. root	4.6	Khan and Frankland. 1984
Cadmium	Brown earth soil	CdO	Radish	42		100	LCT	Dry wgt. root/shoot	5.4	Khan and Frankland. 1983.
Cadmium	Brown earth soil	CdCl2	Wheat	42		50	LCT	Dry wgt. root	4.6	Khan and Frankland. 1984
Cadmium	Humic sand	CdCl2	Tomato	14		171	EC50%	Fresh wgt. shoot	5.1	Adema and Henzen. 1989
Cadmium	Humic sand	CdCl2	Lettuce	14		136	EC50%	Fresh wgt. shoot	5.1	Adema and Henzen. 1989.
Cadmium	Humic sand	CdCl2	Oat	14		97	EC50%	Fresh wgt. shoot	5.1	Adema and Henzen. 1989.
Cadmium	Loam	CdCl2	Oat	14		159	EC50%	Dry wgt. leaves	7.5	Adema and Henzen. 1989.
Cadmium	Loam	CdCl2	Tomato	14		16	EC50%	Fresh wgt. shoot	7.5	Adema and Henzen. 1989.
Cadmium	Loam	CdCl2	Lettuce	14		33	EC50%	Fresh wgt. shoot	7.5	Adema and Henzen. 1989.
Cadmium	Loamy sand		Corn	31		2.5	LCT	Dry wgt. shoot	6	Miller, et al. 1977.
Cadmium	Loamy sand	CdCl2	Corn	5	15	25		Root length	6.5	Hassett, et al. 1976.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Cadmium	Loamy sand		Spinach	70	2	4		Dry wgt. plant	8.3	Sadana and Singh. 1987b.
Cadmium	Loamy sand		Wheat			10	LCT	Yield grain	8.4	Sadana and Singh. 1987a.
Cadmium	Sand	CdCl2	Bluestem	84		10	LCT	Dry wgt. root/shoot	7.8	Miles and Parker. 1979.
Cadmium	Sand	CdCl2	Corn	35		28	LCT	Dry wgt. plant	5	Traynor and Knezek. 1973
Cadmium	Sand culture	CdCl2	Red alder	77	0.031	0.062		Dry wgt. root/stem		Wickliff and Evans. 1980.
Cadmium	Sandy loam	CdCl2	Red oak	112	20	50		Dry wgt. plant	6	Dixon. 1988.
Cadmium	Sandy+clay loams	CdCl2	Wheat	45	10	20		Yield grain/straw	8.4	Singh, et al. 1991.
Cadmium	Silica sand	CdCl2	Red alder	77		0.061	LCT	Dry wgt. stem/leaves		Wickliff, et al. 1980.
Cadmium	Silica sand	CdCl2	Silver Maple	56		5	LCT	Dry wgt. root/leaf/stem		Lamoreaux and Chaney. 1977
Cadmium	Silty clay loam	CdCl2	Lettuce	37		2.5	LCT	Dry wgt. plant	6.7	Haghiri. 1973
Cadmium	Silty clay loam	CdCl2	Soybean	35	5	10		Dry wgt. shoot	6.7	Haghiri. 1973.
Cadmium	Silty clay loam	CdCl2	Sycamore	90		5	LCT	Leaf biomass		Carlson and Bazzaz. 1977
Cadmium	Silty clay loam	CdCl2	Radish	26		2.5	LCT	Dry wgt. root	6.7	Haghiri. 1973.
Cadmium	Silty clay loam	CdCl2	Wheat	35	2.5	5		Dry wgt. shoot	6.7	Haghiri. 1973.
Cadmium	Soil	CdCl2	Soybean		5	10		Seeds per plant		Aery and Sakar. 1991
Cadmium	Soil + sand (1:1)	CdCl2	Spruce	100	1	2		Dry wgt. root/shoot	3.3	Burton, et al. 1984.
Cadmium	Solution	CdCl2	Swiss chard	35	0.1	1		Dry wgt. shoot	6.3	Turner. 1973.
Cadmium	Solution	CdSO4	Tomato	21		1	LCT	Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdSO4	Chrysanthemum	21		0.112	LCT	Dry wgt. root/stem		Patel, et al. 1976.
Cadmium	Solution	CdCl2	Rye	10	50	100		Dry wgt. shoot	5.9	Carlson and Rolfe. 1979.
Cadmium	Solution	CdSO4	Bean	21		0.1	LCT	Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdSO4	Bean	15	0.06	6.1		Dry wgt. root/leaves	5	Wallace. 1979.
Cadmium	Solution	CdCl2	Tomato	14		3	EC50%	Fresh wgt. shoot		Adema and Henzen. 1989.
Cadmium	Solution	CdSO4	Pepper	21		1	LCT	Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdSO4	Turnip	21		0.1	LCT	Dry wgt. plant		Page, et al. 1972.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Cadmium	Solution	CdSO4	Barley	21		1	LCT	Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdSO4	Lettuce	21		1	LCT	Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdSO4	Corn	10		0.112	LCT	Fresh wgt. plant		Stiborova, et al. 1986.
Cadmium	Solution	CdCl2	Oat	14		6	EC50%	Fresh wgt. shoot		Adema and Henzen. 1989.
Cadmium	Solution	CdCl2	Lettuce	14		0.84	EC50%	Fresh wgt. shoot		Adema and Henzen. 1989.
Cadmium	Solution	CdCl2	Beetroot	35	0.1	1		Dry wgt. shoot	6.3	Turner. 1973.
Cadmium	Solution	CdCl2	Carrot	35		0.01	LCT	Dry wgt. shoot	6.3	Turner. 1973.
Cadmium	Solution	CdSO4	Cabbage	21	1	2.5		Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdSO4	Corn	21	0.25	0.5		Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdSO4	Rye grass	14		1.25	LCT	Lgth.longest root/shoot	7	Wong and Bradshaw. 1982.
Cadmium	Solution	Cd(NO3)2	Soybeans	21		0.05	LCT	Dry wgt. root/leaves	6.2	Cunningham. 1977.
Cadmium	Solution	CdSO4	Beet	21		0.1	LCT	Dry wgt. plant		Page, et al. 1972.
Cadmium	Solution	CdCl2	Tomato	14	0.01	0.1		Dry wgt. shoot	6.3	Turner. 1973
Chromium	Humic sand	K2Cr2O7	Tomato	14		21	EC50%	Fresh wgt. shoot	5.1	Adema and Henzen. 1989
Chromium	Humic sand	K2Cr2O7	Oat	14		31	EC50%	Fresh wgt. shoot	5.1	Adema and Henzen. 1989.
Chromium	Humic sand	K2Cr2O7	Lettuce	14		>11	EC50%	Fresh wgt. shoot	5.1	Adema and Henzen. 1989.
Chromium	Loam	K2Cr2O7	Soybean	3	10	30		Fresh wgt. shoot		Turner and Rust. 1971.
Chromium	Loam	K2Cr2O7	Tomato	14		6.8	EC50%	Fresh wgt. shoot	7.5	Adema and Henzen. 1989.
Chromium	Loam	K2Cr2O7	Oat	14		7.4	EC50%	Fresh wgt. shoot	7.5	Adema and Henzen. 1989.
Chromium	Loam	K2Cr2O7	Lettuce	14		1.8	EC50%	Fresh wgt. shoot	7.5	Adema and Henzen. 1989.
Chromium	Solution	CrCl3+K2CrO4	Cabbage	55	2	10		Dry wgt. plant	5	Hara, et al. 1976.
Chromium	Solution	K2Cr2O7	Soybean	5	0.5	1		Dry wgt. shoot		Turner and Rust. 1971.
Chromium	Solution	CrSO4	Chrysanthemum	21		0.052	LCT	Dry wgt. stem/leaves		Patel, et al. 1976.
Chromium	Solution	K2Cr2O7	Lettuce	14		0.16	EC50%	Fresh wgt. shoot		Adema and Henzen. 1989.
Chromium	Solution	Cr2(SO4)3	Rye grass	2.5	10	50		% seed gemination		Breeze. 1973

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Chromium	Solution	K2Cr2O7	Oat	14		1.4	EC50%	Fresh wgt. shoot		Adema and Henzen. 1989.
Chromium	Solution	Cr2K2O7	Rye grass	2.5	10	50		% seed germination		Breeze. 1973.
Chromium	Solution	K2Cr2O7	Rye grass	14		2.5	LCT	Lgth. longest root	7	Wong and Bradshaw. 1982.
Chromium	Solution	K2Cr2O7	Bush beans	11		0.27	LCT	Dry wgt. leaf		Wallace, et al. 1977a.
Chromium	Solution	K2Cr2O7	Tomato	14		0.29	EC50%	Fresh wgt. shoot		Adema and Henzen. 1989.
Cobalt	Solution	CoSO4	Bush beans	21		0.06	LCT	Dry wgt. leaves		Wallace, et al. 1977a.
Cobalt	Surface soil					25		Phytotoxic		Linzon. 1978.
Cobalt	Solution	CoSO4	Chrysanthemum	21		0.059	LCT	Dry wgt. root		Patel, et al. 1976.
Copper	Loam	CuSO4	Bush beans	17	100	200		Dry wgt. leaves		Wallace, et al. 1977b
Copper	Sand	CuSO4	Bluestem	84		100	LCT	Dry wgt. root/shoot	7.8	Miles and Parker. 1979.
Copper	Sand	CuSO4	Bluestem	84		100	LCT	Dry wgt. root/shoot	4.8	Miles and Parker. 1979.
Copper	Soil		Clover	120		40	LCT	Phytotoxic		Dvorak, et al. 1978
Copper	Solution	CuSO4	Rice	4	2.53	25.3		Root length		Gupta and Mukherji. 1977.
Copper	Solution	CuSO4	Tobacco	21	0.16	0.32		Dry wgt. root/shoot		Struckmeyer, et al. 1969
Copper	Solution	CuSO4	Rye grass	14		0.031	LCT	Lgth. longest root	7	Wong and Bradshaw. 1982
Copper	Solution	CuSO4	Corn	10		0.064	LCT	Fresh wgt. plant		Stiborova, et al. 1986.
Copper	Surface soil					60		Phytotoxic		Kovalskiy. 1974
Copper	Solution	CuSO4	Chrysanthemum	21		0.064	LCT	Dry wgt. root		Patel, et al. 1976
Dinitrophenol, 2,4	Clay		Fescue	21	20	40		Fresh wgt. shoot	4.75	Overcash, et al. 1982.
Dinitrophenol, 2,4	Clay		Corn	21	20	40		Fresh wgt. shoot	4.75	Overcash, et al. 1982.
Dinitrophenol, 2,4	Clay		Soybeans	21		20	LCT	Fresh wgt. shoot	4.75	Overcash, et al. 1982.
Dinitrophenol, 2,4	Sandy loam		Soybean		20	40		% seed germination	4	Overcash, et al. 1982.
Dinitrophenol, 2,4	Sandy loam		Fescue	21	60	80		Fresh wgt. shoot	6	Overcash, et al. 1982.
Dinitrophenol, 2,4	Sandy loam		Corn		60	80		% seed germination	4	Overcash, et al. 1982.
Dinitrophenol, 2,4	Sandy loam		Fescue	21	20	40		Fresh wgt. shoot	4	Overcash, et al. 1982.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Dinitrophenol, 2,4	Sandy loam		Corn	21	20	40		Fresh wgt. shoot	6	Overcash, et al. 1982.
Dinitrophenol, 2,4	Sandy loam		Soybeans	21	20	40		Fresh wgt. shoot	4	Overcash, et al. 1982.
Dinitrophenol, 2,4	Sandy loam		Corn	21		20	LCT	Fresh wgt. shoot	4	Overcash, et al. 1982.
Dinitrophenol, 2,4	Sandy loam		Soybeans	21		20	LCT	Fresh wgt. shoot	6	Overcash, et al. 1982.
Di-n-butyl phthalate	Clay		Fescue	21	200	2000		Fresh wgt. shoot	4.75	Overcash, et al. 1982.
Di-n-butyl phthalate	Clay		Corn	21		200	LCT	Fresh wgt. shoot	4.75	Overcash, et al. 1982.
Di-n-butyl phthalate	Sandy loam		Corn	21		200	LCT	Fresh wgt. shoot	5.75	Overcash, et al. 1982.
Di-n-butyl phthalate	Sandy loam		Fescue	21	200	2000		Fresh wgt. shoot	5.75	Overcash, et al. 1982.
Di-n-butyl phthalate	Sandy loam		Soybean	21		200	LCT	Fresh wgt. shoot	5.75	Overcash, et al. 1982.
Di-n-butyl phthalate	Sandy loam		Soybean			200	LCT	% seed germination	4	Overcash, et al. 1982.
Di-n-butyl phthalate	Sandy loam		Corn	21		200	LCT	Fresh wgt. root/shoot	4	Overcash, et al. 1982.
Fluorine	Surface soil					200		Phytotoxic		Kloke. 1979.
Fluorine	Solution					5	LCT	Phytotoxic		Scharrer 1955.
Iodine	Loam	KI	Tomato	95	0.45	4.5		Dry wgt. shoot	6.75	Newton and Toth. 1952.
Iodine	Sand	KI	Tomato	95	0.45	4.5		Dry wgt. shoot	6.75	Newton and Toth. 1952.
Iodine	Silt loam	KI	Tomato	95	0.45	4.5		Dry. wgt. shoot	6.75	Newton and Toth. 1952.
Iodine	Silt loam	KI	Tomato	95	0.45	4.5		Dry wgt. shoot	6.75	Newton and Toth. 1952.
Iodine	Solution	KI	Tomato	60	0.5	5		Dry wgt. shoot		Newton and Toth. 1952.
Iodine	Solution	KI	Corn	60	0.1	0.5		Dry wgt. shoot	5.8	Lewis and Powers. 1941
Iron	Solution	FeSO4	Bush beans	15	11.6	29		Dry wgt. root/leaf/stem		Wallace, et al. 1977b.
Iron	Solution	FeSO4	Cabbage	55	10	50		Dry wgt. plant	5	Hara, et al. 1976.
Iron	Solution					10	LCT	Phytotoxic		Chapman. 1966.
Lead	Brown earth soil	PbCl2	Wheat	42	500	1000		Dry wgt. root	4.6	Khan and Frankland 1984.
Lead	Brown earth soil	PbCl2	Oat	42	100	500		Dry wgt. root	5.4	Khan and Frankland. 1984.
Lead	Loamy sand	PbCl2	Corn	5	250	500		Root length	6.5	Hassett, et al. 1976.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Lead	Loamy sand		Corn	31	125	250		Dry wgt. plant	6	Miller, et al. 1977.
Lead	Sand	PbCl2	Bluestem	84		450	LCT	Dry wgt. root/shoot	7.8	Miles and Parker. 1979.
Lead	Sand	PBCl2	Bluestem	84		450	LCT	Dry wgt. root	4.8	Miles and Parker. 1979.
Lead	Sandy loam	CdCl2	Red oak	112	20	50		Dry wgt. plant	6	Dixon. 1988.
Lead	Silt loam	PbCl2	Rye	10	100	5000		Dry wgt. shoot	5.9	Carlson and Rolfe. 1979.
Lead	Silty clay loam	PbCl2	Sycamore	90		50	LCT	Leaf biomass		Carlson and Bazzaz. 1977.
Lead	Solution	Pb(NO3)2	Wire grass	14		10	LCT	Root length		Wong and Lau. 1985.
Lead	Solution	Pb(NO3)2	Bermuda grass	14		10	LCT	Root length		Wong and Lau. 1985.
Lead	Solution	Pb(NO3)2	Bermuda grass	14		10	LCT	Root length		Wong and Lau. 1985.
Lead	Solution	PbSO4	Bean	28	5	10		Dry wgt. plant		Hooper. 1937.
Lead	Solution	Pb(NO3)2	Rye grass	14		2.5	LCT	Lght.longest root/shoot		Wong and Bradshaw. 1982.
Lead	Solution	Pb(NO3)2	Wire grass	14	10	20		Root length		Wong and Lau. 1985.
Lead	Solution	PbSO4	Bean	28	5	10		Dry wgt. plant		Hooper. 1937.
Lead	Solution	PbSO4	Bean	28	5	10		Dry wgt. plant		Hooper. 1937.
Lead	Solution	PbSO4	Bean	28	20	30		Dry wgt. plant		Hooper. 1937.
Lead	Solution	PbSO4	Bean	28	20	30		Dry wgt. plant		Hooper. 1937.
Lead	Solution	Pb(NO3)2	Wire grass	14		10	LCT	Root length		Wong and Lau. 1985.
Lead	Solution	Pb(NO3)2	Corn	10	20.7	207		Fresh wgt. plant		Stiborova, et al. 1986.
Lead	Solution	Pb(NO3)2	Bermuda grass	14		10	LCT	Root length		Wong and Lau. 1985.
Lead	Alluvial soil	PbCl2	Wheat	161	1000	3000		Dry wgt. root/shoot	5.95	Muramoto. 1990.
Lead	Brown earth soil	PbCl2	Radish	42	100	500		Dry wgt. root	5.4	Khan and Frankland. 1983.
Lead	Brown earth soil	PbO	Radish	42		1000	LCT	Dry wgt. root	5.4	Khan and Frankland. 1983.
Lead	Silt loam	PbCl2	Fescue	10	1000	5000		Dry wgt. shoot	5.9	Carlson and Rolfe. 1979.
Lead	Soil + sand (1:1)	PbCl2	Spruce	100	50	100		Dry wgt. root/shoot	3.3	Burton, et al. 1984.
Lithium	Loam	LiNO3	Cotton	21	25	50		Dry wgt. leaf/stem		Wallace, et al. 1977c.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Lithium	Loam	LiCl	Bush beans	16	10	25		Dry wgt. leaf		Wallace, et al. 1977c.
Lithium	Loam	Li2C2O4	Barley	10		500	LCT	Dry wgt. shoot	6	Wallace. 1979.
Lithium	Soil		Orange	180		2		Phytotoxic		Aldrich, et al. 1951.
Lithium	Solution	LiNO3	Bush beans	24		3.5	LCT	Dry wgt. stem		Wallace, et al. 1977c.
Manganese	Loam	MnSO4	Bush beans	14		500	LCT	Dry wgt. stems		Wallace, et al. 1977b.
Manganese	Quartz sand	MnSO4	Siratro	76		30	LCT	Dry wgt. plant	4.2	Hutton, et al. 1978.
Manganese	Quartz sand	MnSO4	Siratro	76		30	LCT	Dry wgt. plant	4.2	Hutton, et al. 1978.
Manganese	Quartz sand	MnSO4	Siratro	76		30	LCT	Dry wgt. plant	4.2	Hutton, et al. 1978.
Manganese	Quartz sand	MnSO4	Siratro	76	30	45		Dry wgt. plant	4.2	Hutton, et al. 1978.
Manganese	Quartz Sand	MnSO4	Siratro	76		30	LCT	Dry wgt. plant	4.2	Hutton, et al. 1978.
Manganese	Solution	MnSO4	Spruce	32	11	44		Root length	6	Langheinrich, et al. 1992.
Manganese	Solution	MnSO4	Bush beans	16		5.5	LCT	Dry wgt. root/leaf/stem		Wallace, et al. 1977b.
Manganese	Solution	MnSO4	Wheat	30	30	90		Dry wgt. root/shoot	4.8	Burke, et al. 1990.
Manganese	Solution	MnSO4	Bush beans	21	5.4	54		Dry wgt. root/leaf/stem		Wallace, et al. 1977b.
Manganese	Solution	MnSO4	Spruce	32	11	44		Rel. gwth. rate	6	Langheinrich, et al. 1992.
Manganese	Solution	MnSO4	Spruce	77		44	LCT	Hgt. epicotyl	4	Langheinrich et al. 1992.
Manganese	Solution	MnSO4	Wheat	30		30	LCT	Dry wgt. root	4.8	Burke, et al. 1990.
Manganese	Solution	MnSO4	Wheat	30		30	LCT	Dry wgt. root	4.8	Burke, et al. 1990.
Manganese	Solution	MnSO4	Spruce	77		44	LCT	Hgt. epicotyl	4	Langheinrich et al. 1992.
Manganese	Solution	MnSO4	Tomato	17	2.75	5.49		Dry wgt. plant	5.5	Le Bot, et al. 1990.
Manganese	Solution	MnSO4	Wheat	30		30	LCT	Dry wgt. root/shoot	4.8	Burke, et al. 1990.
Manganese	Solution	MnSO4	Rye grass	14		0.75	LCT	Lgth. longest root	7	Wong and Bradshaw. 1982.
Manganese	Solution	MnSO4	Wheat	30		30	LCT	Dry wgt. root	4.8	Burke, et al. 1990.
Manganese	Solution	MnSO4	Bean	21	2	20		Dry wgt. root/leaves	5	Wallace. 1979.
Mercury	Soil					0.3	LCT	Phytotoxic		Kloke. 1979.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Mercury	Solution	CH3HgCl	Spruce	35		0.02	LCT	Chlorophyll in needles	4.3	Schlegel, et al. 1987.
Mercury	Solution	HgCl2	Rye grass	14		5	LCT	Lgth.longest root/shoot	7	Wong and Bradshaw. 1982.
Mercury	Solution	HgCl2	Spruce	35		0.02	LCT	Chlorophyll in needles	4.3	Schlegel, et al. 1987.
Mercury	Solution	Ch3HgCl	Spruce	35		0.002	LCT	Transp. rate/CO2 uptake	4.3	Schlegel, et al. 1987.
Molybdenum	Soil					2	LCT	Phytotoxic		Linzon. 1978.
Molybdenum	Solution					0.5	LCT	Phytotoxic		Chapman. 1966.
Molybdenum	Solution	H2MoO4	Bean	14		5.72	LCT	Dry wgt. leaves	5	Wallace. 1979.
Molybdenum	Solution	H2MoO4	Bush beans	14		9.6	LCT	Dry wgt. leaf		Wallace, et al. 1977b.
Nickel	Loam	NiSO4	Corn	19	100	250		Dry wgt. shoot	4.2	Wallace, et al. 1977d.
Nickel	Loam	NiSO4	Bush beans	16	100	250		Dry wgt. shoot	7.5	Wallace, et al. 1977d.
Nickel	Loam	NiSO4	Corn	19	100	250		Dry wgt. shoot	5.6	Wallace, et al. 1977d.
Nickel	Loam	NiSO4	Corn	19	100	250		Dry wgt. shoot		Wallace, et al. 1977d.
Nickel	Loam	NiSO4	Bush beans	28		100	LCT	Dry wgt. leaves		Wallace, et al. 1977d.
Nickel	Loam	NiSO4	Barley	28		25	LCT	Dry wgt. shoot		Wallace, et al. 1977d.
Nickel	Loam	NiSO4	Corn	19	100	250		Dry wgt. shoot	4.2	Wallace, et al. 1977d.
Nickel	Loam	NiSO4	Bush beans	16		100	LCT	Dry wgt. shoot	5.8	Wallace, et al. 1977d.
Nickel	Sand	NiCl2	Corn	35	220	294		Dry wgt. plant	5	Traynor and Knezek. 1973.
Nickel	Sandy loam	NiCl2	Red Oak	112	20	50		Dry wgt. plant	6	Dixon. 1988.
Nickel	Solution	NiSO4	Rye grass	14		0.13	LCT	Lgth. longest root	7	Wong and Bradshaw. 1982.
Nickel	Solution	NiSO4	Chrysanthemum	21	0.06	0.59		Dry wgt. stem/leaves		Patel, et al. 1976.
Nickel	Loam	NiSO4	Rye grass	28	90	180		Dry wgt. shoot	4.7	Khalid and Tinsley. 1980.
Nickel	Solution		Bean	21		1.17	LCT	Dry wgt. root/leaves	5	Wallace. 1979.
PCB	Sand	Aroclor 1254	Soybean	26	10	100		Fresh wgt. shoot	4.7	Weber and Mrozek. 1979.
PCB	Sand	Aroclor 1254	Soybean			1000	LCT	Fresh wgt. shoot	4.7	Strek and Weber. 1980.
PCB	Sand	Aroclor 1254	Pigweed		40	100		Fresh wgt. shoot/p.hgt.	4.7	Strek and Weber. 1980.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
PCB	Sand	Aroclor 1254	Soybean			1000	LCT	Fresh wgt. shoot	4.7	Strek and Weber. 1980.
PCB	Sand	Aroclor 1254	Pigweed		20	40		Fresh wgt. shoot/p.hgt.	4.7	Strek and Weber. 1980.
PCB	Sand	Aroclor 1254	Soybean			1000	LCT	Fresh wgt. shoot/p.hgt.	4.7	Strek and Weber. 1980.
PCB	Sand	Aroclor 1254	Pigweed	28	50	100		Plant height	4	Strek and Weber. 1982.
PCB	Sand	Aroclor 1254	Soybean			1000	LCT	Fresh wgt. shoot/p.hgt.	4.7	Strek and Weber. 1980.
Selenium	Loamy sand	Na2SeO4	Sorgrass	42		1	LCT	Dry wgt. shoot	5.5	Carlson, et al. 1991.
Selenium	Sand	Na2SeO4	Sorgrass	42		1	LCT	Dry wgt. shoot	4.9	Carlson, et al. 1991.
Selenium	Sand	Na2SeO4	Sorgrass	42		1	LCT	Dry wgt. shoot	6.5	Carlson, et al. 1991.
Selenium	Sand	Na2SeO3	Sorgrass	42	1	2		Dry wgt. shoot	4.9	Carlson, et al. 1991.
Selenium	Silica sand	Na2SeO4	Rye grass	60	7.7	10.3		Dry wgt. plant		Smith and Watkinson. 1984.
Selenium	Silica sand	Na2SeO4	Clover	60	10.3	12.9		Dry wgt. plant		Smith and Watkinson. 1984
Selenium	Silica sand	Na2SeO3	Rye grass	60	7.7	10.3		Dry wgt. plant		Smith and Watkinson. 1984.
Selenium	Solution	Na2SeO3	Wheat	42		1	LCT	Dry wgt. root/shoot:hgt		Martin. 1936.
Selenium	Solution	Na2SeO3	Milk-vetch		9	27		Dry wgt. plant		Trelease and Trelease. 1938
Selenium	Solution	Na2SeO3	Buckwheat	42		1	LCT	Dry wgt. root/shoot:hgt		Martin. 1936
Selenium	Loamy sand	Na2SeO4	Sorgrass	42		1	LCT	Dry wgt. shoot	6	Carlson, et al. 1991.
Silver	Soil					2	LCT	Phytotoxic		Linzon. 1978.
Silver	Solution	AgNO3	Bean	13		0.068	LCT	Dry wgt. leaf	5	Wallace. 1979.
Silver	Solution	AgNO3	Bush beans	13		0.17	LCT	Dry wgt. plant		Wallace, et al. 1977a.
Tellurium	Solution	K2TeO3	Wheat	42		2	LCT	Dry wgt. root/shoot		Martin. 1937.
Thallium	Quartz sand	TlNO3	Tobacco	30	0.1	0.3		Fresh wgt. shoot		Spencer. 1937
Thallium	Solution					1	LCT	Phytotoxic		Stiles. 1958.
Thallium	Surface soil					1		Phytotoxic		Kloke. 1979.
Tin	Solution					40		Phytotoxic		Schroeder. 1955.
Tin	Surface soil					50		Phytotoxic		Kloke. 1979.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Titanium	Solution	TiCi3	Cabbage	55	0.4	4		Dry wgt. plant	5	Hara, et al. 1976.
Titanium	Solution	TiCl3	Bush beans	21		0.069	LCT	Dry wgt. leaves		Wallace, et al. 1977a.
Toluene	Clay		Soybean	21	2000	20000		Fresh wgt. shoot	4.75	Overcash, et al. 1982.
Toluene	Clay		Corn	21		200	LCT	Fresh wgt. shoot	4.75	Overcash, et al. 1982.
Toluene	Sandy loam		Corn		2000	20000		% seed germination	4	Overcash, et al. 1982.
Toluene	Sandy loam		Corn	21	2000	20000		Fresh wgt. shoot	5.75	Overcash, et al. 1982.
Toluene	Sandy loam		Fescue	21	2000	20000		Fresh wgt. shoot	5.75	Overcash, et al. 1982.
Toluene	Sandy loam		Soybean	21		200	LCT	Fresh wgt. shoot	5.75	Overcash, et al. 1982.
Toluene	Sandy loam		Soybean		200	2000		% seed germination	4	Overcash, et al. 1982.
Vanadium	Sand		Corn	67	1.25	6.25		Plant hgt./leaf area		Singh. 1971.
Vanadium	Soil					2.5	LCT	Phytotoxic		EPA. 1975.
Vanadium	Solution	VCl3	Cabbage	55	0.4	4		Dry wgt. plant	5	Hara, et al. 1976.
Vanadium	Solution	NH4VO3	Bush beans	14		1.17	LCT	Dry wgt. roots		Wallace, et al. 1977
Vanadium	Solution	NH4VO3	Bean	14		0.22	LCT	Dry wgt. root	5	Wallace. 1979.
Vanadium	Surface soil					50		Phytotoxic		Kloke. 1979.
Zinc	Alluvial soil	ZnO	Rice	105		1000	LCT	Dry wgt. root	5.95	Muramoto. 1990.
Zinc	Clay loam	ZnSO4	Cowpea	31	157.82	315.94		Dry wgt. shoot		Gall and Barnette. 1940
Zinc	Clay loam	ZnSO4	Corn	31	473.76	631.58		Dry wgt. shoot		Gall and Barnette. 1940
Zinc	Fine sandy loam	ZnSO4	Cowpea	31	111.8	222.36		Dry wgt. shoot		Gall and Barnette. 1940
Zinc	Fine sandy loam	ZnSO4	Corn	31	222.36	333.54		Dry wgt. shoot		Gall and Barnette. 1940
Zinc	Sand	ZnSO4	Corn	31	201.83	403.65		Dry wgt. shoot		Gall and Barnette. 1940
Zinc	Sand	ZnSO4	Cowpea	31	80.67	141.4		Dry wgt. shoot		Gall and Barnette. 1940
Zinc	Sand	ZnSo4	Cotton	77		140	LCT	Dry wgt. shoot	5.5	Lee and Page. 1967.
Zinc	Sandy loam		Peanut	105	14	17		Dry wgt. plant		Keisling, et al. 1977.
Zinc	Sandy loam	ZnSO4	Soybean	28	115	131		Dry wgt. leaves	5.5	White, et al. 1979.

Table 1. (continued)

CHEMICAL	GROWTH MEDIUM	FORM	SPECIES	DURATION	NOEC	LOEC	NOTES	GROWTH PARAMETER	pH	REFERENCE
Zinc	Sandy loam	ZnSO4	Soybean	28	327	393		Dry wgt. leaves	6.5	White, et al. 1979.
Zinc	Soil	ZnSO4	Spinach	60		87.2	LCT	Dry wgt. root/shoot		Lata and Veer. 1990.
Zinc	Soil	ZnSO4	Soybean		10	25		Seeds per plant		Aery and Sakar. 1991.
Zinc	Solution		Clover	46	0.082	0.41		Dry wgt. plant	6	Carroll and Loneragan. 1968.
Zinc	Solution		Barrel medic	46	0.082	0.41		Dry wgt. plant	6	Carroll and Loneragan. 1968.
Zinc	Solution		Lucerne	46	0.082	0.41		Dry wgt. plant	6	Carroll and Loneragan. 1968.
Zinc	Solution	ZnSO4	Chrysanthemum	21	0.65	6.5		Dry wgt. stem		Patel, et al. 1976.
Zinc	Solution	ZnSO4	Bush beans	16	1.62	16.2		Dry wgt. root/shoot		Wallace, et al. 1977b.
Zinc	Solution	ZnSO4	Rye grass	14		1.85	LCT	Lgth. longest root	7	Wong and Bradshaw. 1982
Zinc	Alluvial soil	ZnO	Wheat	161		1000	LCT	Dry wgt. plant/grain yld.	5.95	Muramoto. 1990.
Zinc	Soil	ZnSO4	Coriander	60		87.2	LCT	Dry wgt. root/shoot		Lata and Veer. 1990.

Table 2. Screening benchmark concentrations for the phytotoxicity of chemicals in soil and soil solution (Letters after concentrations denote values said in secondary sources to represent phytotoxicity thresholds)

CHEMICAL	SOIL (mg/kg)	SOLUTION (mg/L)
Aluminum	10	0.5
Antimony	5[a]	--
Arsenic	10	0.02[b]
Barium	500	500[c]
Beryllium	10[a]	0.5
Bismuth	--	27[b]
Boron	0.5	1[d]
Bromine	10[a]	15[c]
Cadmium	2	0.1
Chromium	2	0.05
Cobalt	25[e]	0.06
Copper	40[f]	0.03
Fluorine	200[a]	5[b]
Iodine	4	0.5
Iron	--	10[c]
Lead	50	10
Lithium	2	3
Manganese	500	1
Methyl mercury	--	0.002
Mercury	0.3	0.02
Molybdenum	2[c]	0.5[c]
Nickel	25	0.1
Selenium	1	1
Silver	2[e]	0.07
Tellurium	--	2
Thallium	1[a]	1[g]
Tin	50[a]	40[h]

Table 2. (continued)

CHEMICAL	SOIL (mg/kg)	SOLUTION (mg/L)
Titanium	--	0.07
Vanadium	2.5[i]	0.2
Zinc	20	0.4
2,4 Dinitrophenol	20	--
Di-n-butyl phthalate	200	--
PCBs	40	--
Toluene	200	--

[a] Kloke, 1979; [b] Scharrer, 1955; [c] Chapman, 1966; [d] Bowen, 1979; [e] Linzon, 1978; [f] Dvorak et al., 1978; [g] Stiles, 1958; [h] Schroeder, 1955; [i] EPA, 1975.

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